

EUVS PROJECT MEMORANDUM

Date: May 31, 1996
Project: EUVS Sounding Rocket payload (SwRI Project 15-5726)
Memo #: 15-5726-DS05.31.96
From: D. Slater, EUVS Project Manager, x2205
Subject: EUVS Project Semi-Annual Progress Report (Jan. - May 1996)

During the first half of this year (CY 1996), the EUVS project began preparations of the EUVS payload for the upcoming NASA sounding rocket flight 36.148CL, slated for launch on July 26, 1996 to observe and record a high-resolution ($\sim 2 \text{ \AA}$ FWHM) EUV spectrum of the planet Venus. These preparations were designed to improve the spectral resolution and sensitivity performance of the EUVS payload as well as prepare the payload for this upcoming mission. The following is a list of the EUVS project activities that have taken place since the beginning of this CY:

- Applied a fresh, new SiC optical coating to our existing 2400 groove/mm grating to boost its reflectivity;
- modified the Ranicon science detector to boost its detective quantum efficiency with the addition of a repeller grid;
- constructed a new entrance slit plane to achieve 2 \AA FWHM spectral resolution;
- prepared and held the Payload Initiation Conference (PIC) with the assigned NASA support team from Wallops Island for the upcoming 36.148CL flight (PIC held on March 8, 1996; see Attachment A);
- began wavelength calibration activities of EUVS in the laboratory;
- made arrangements for travel to WSMR to begin integration activities in preparation for the July 1996 launch;
- paper detailing our previous EUVS Venus mission (NASA flight 36.117CL) published in *Icarus* (see Attachment B);
- continued data analysis of the previous EUVS mission 36.137CL (Spica occultation flight).

All tasks to ready the EUVS payload for the next sounding rocket mission (36.148CL) are on schedule. We expect no delays or schedule problems.

Xc: S. Alan Stern, SwRI BEO
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2 Attachments

ATTACHMENT A

PIC DOCUMENT FOR EUVS MISSION 36.148CL

TARGET: VENUS

SECTIONS 1 & 2

**Principle Investigators Data Package
for
Project Initiation Conference (PIC)**

March 8, 1996

**NASA Wallops Flight Facility
Wallops Island, Virginia**

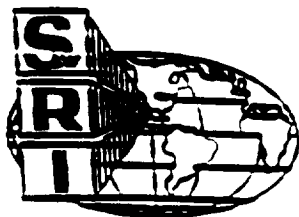
EUVS Sounding Rocket

Flight 36.148CL

Target: Venus

Principal Investigator

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List of Acronyms

ACS	Attitude Control System
AU	Astronomical Unit
CCD	Charge-Coupled Device
CDR	Critical Design Review
EUV	Extreme Ultraviolet
EUVS	Extreme Ultraviolet Spectrograph
FGC	Fine Guidance Camera
FOV	Field-of-View
FWHM	Full-Width-at-Half-Maximum
GSE	Ground Support Equipment
HV	High-Voltage
HVPS	High-Voltage Power Supply
KBr	Potassium Bromide
LED	Light Emitting Diode
LiF	Lithium Fluoride
LV	Low-Voltage
MCP	Microchannel Plate
NASA	National Aeronautics and Space Administration
PSF	Point Spread Function
PVS	Payload Vacuum System
QE	Quantum Efficiency
SiC	Silicon Carbide
SNR	Signal-to-Noise Ratio
SwRI	Southwest Research Institute
TM	Telemetry
UTC	Coordinated Universal Time
WFF	Wallops Flight Facility

1. INTRODUCTION

We are conducting a program of rocket-borne suborbital research to make spectroscopic studies of planetary atmospheres in the far ultraviolet. Our flight program leverages an existing, flight-proven far ultraviolet telescope/detector system (EUVS—Extreme Ultraviolet Spectrograph) developed by funding from the NASA Astrophysics Division to conduct exciting, cost-effective planetary research. Our program consists of reflights, after modest instrument upgrades which improve sensitivity and resolution. The Venus observations we plan to conduct cannot be achieved from any existing or planned orbital observatory, or by ground-based means. As such, the rocket research we are conducting makes a unique contribution to planetary astronomy.

The EUVS sounding rocket payload flew twice in 1994 and once in 1995 (Slater *et al.* 1995). All three flights were successful. On the first flight we observed Jupiter and the Io torus during the comet Shoemaker-Levy 9 impacts (36.121CL, 20 July 1994; Stern *et al.* 1995). During the second flight, we observed the planet Venus (36.117CL, 15 August 1994; Stern *et al.* 1996) and obtained the highest-resolution extreme ultraviolet (EUV) spectrum of Venus ever recorded. On the third flight (36.137CL, 15 April 1995), EUVS observed the lunar occultation of the bright star Spica in an attempt to detect and measure various constituent gases that make up the lunar atmosphere. The payload performed flawlessly and was recovered in good condition after each flight.

We plan to refly the EUVS sounding rocket payload in July or August 1996 with Venus as the primary target. The primary objective of this next flight will be to conduct a more detailed investigation of Venus' thermospheric extreme ultraviolet (EUV) emissions as a follow-up to our 1994 investigation. This flight will achieve 30 to 60% better signal-to-noise ratio (S/N) with a spectral resolution of ~ 3 Å which is more than twice the spectral resolving power of our first Venus flight in 1994 (NASA Flight 36.117CL).

To achieve the higher S/N and spectral resolving power we plan to make the following modifications to EUVS:

1. *Install a new entrance slit to the spectrograph.* The new slit shall be sized to achieve a 3 Å full-width-at-half-maximum (FWHM) emission line width at the science detector.
2. *Make the EUVS detector repeller grid operational.* This electrical modification to the payload will restore the repeller grid to the operational capability it had before 1994, and will increase the effective area of the instrument by a factor of ~ 1.5 .
3. *Recoat the reflection grating to improve its efficiency.* A new SiC coating will improve the reflective efficiency of the grating by a factor of 1.2, or slightly better, over the present coating.
4. *Launch when Venus is more favorably placed.* In 1994 we launched at a relatively poor geometry for Venus at elongation. We can do much better for this flight in 1996. Throughout the period from mid-June to mid-August, Venus will be better placed than in August 1994. In fact during this time frame, Venus will be brighter by a factor of > 1.2 .
5. *Make trajectory and flight sequence improvements.* We request (i) a Mark 70 booster to achieve a higher apogee, and (ii) to fly without the (75 pound) PCM

experiment carried as a Wallops Island test on 36.117CL and 36.137CL. This will add about 25 seconds to our time on target. Additionally, we plan to (iii) use a more efficient flight pointing profile in which one of our ACS guide stars is our calibration target, thereby reducing the total ACS maneuvering time by about 1/3, and (iv) spend all of integration time using the new, narrower slit (whereas on the 1994 flight we split time between a wide, 16 Å slit, and a narrower 6.4 Å slit). Altogether, we expect to increase the amount of flight integration time on Venus by ~70 seconds, or 45%, over the 1994 flight.

If we did not install the new, high-resolution slit, these factors would give an increase in the total counts at each wavelength by a factor of 2.6 to 4.2. However, the 3 Å slit will decrease the counts by a factor of 1.7. Together, these two opposing factors should net out to give a high-resolution Venus spectrum with 50% to 250% more counts in the 1996 Venus spectrum, than in the 1994, 36.117CL Venus spectrum, depending on the precise launch date and exact performance changes in the instrument and flight profile.

Additional tasks required to ready the payload for flight include: 1) refurbishing the payload for flight; 2) buildup and electrically/mechanically integrating the payload; 3) optically aligning, focusing, and calibrating the payload; 4) taking the payload into the field at WSMR for integration, horizontal tests, spin balance, shake, and vertical tests; and 5) launching and recovering the payload.

2. SCIENTIFIC OBJECTIVES

The spectrum of Venus below 1200 Å had not been well studied prior to the 36.117CL EUVS Venus mission we flew in 1994 (cf., Fox & Bougher 1991). Indeed, the only observations obtained prior to those reported in our paper (Stern *et al.* 1995) were the low-resolution spectrophotometer data from the 1974 Mariner 10 (Broadfoot *et al.* 1974) and 1978 Venera 11 and 12 Venus flybys (Bertaux *et al.* 1981), and the low-resolution spectra obtained during the 1990 Galileo Venus flyby (Hord *et al.* 1991). Those low-resolution observations detected several strong EUV emissions from Venus' upper atmosphere, but the features generating the emissions could not be determined: the spectral resolution was simply too low. Still, although features could not be identified, these early data gave strong indications that Venus' EUV spectrum would be rich in features. Support for the anticipated richness of Venus' EUV spectrum was also generated because Venus' atmosphere, like the Earth's, contains significant populations of O, O⁺, N, N⁺, and N₂, which have complex EUV fluorescence spectra; Venus' atmosphere also contains significant abundances of the EUV-active species CO, C, and C⁺, which are not important in the terrestrial thermosphere.

At 03:25 UT on 15 August 1994 we successfully launched the EUVS instrument payload on a NASA Black Brant IX sounding rocket (36.117CL) from White Sands Missile Range (WSMR), New Mexico, to obtain spectra of Venus in an ~300 Å EUV bandpass centered near 985 Å. By making observations with two different slits, we obtained spectra at resolutions of both 6.4 and 16 Å. As seen from Earth, Venus was 53% illuminated on this date; its diameter was 22.1 arcseconds. The Earth-Venus relative velocity was -13.8 km/sec, which produced a 45 mÅ blueshift in the middle of our bandpass. Since the Doppler widths of telluric thermospheric lines are typically more than 10 times narrower, this was sufficient to prevent strong absorption of Venusian spectral features by corresponding lines in the Earth's upper atmosphere.

At apogee the payload reached an altitude of 255 km; during the flight the zenith angles of Venus and the Sun were 86.7 and 109.7 degrees, respectively. Owing to the proximity of the Sun to both Venus (~ 45 deg), and the Earth's horizon as seen at apogee (~ 4 deg), it was known before flight that the onboard star tracker could not be used to acquire Venus. Instead, we used the attitude control system gyros to guide the telescope to Venus, after gyro updates were made using a star tracker to acquire the stars Vega (α Lyr) and Arcturus (α Boo). Fine pointing of the spectrograph entrance slit on Venus was accomplished using real-time onboard fine guidance video images and a command link from the telemetry ground station at White Sands. The EUVS telescope/spectrograph obtained good data throughout the flight, achieving a spectrum with 5 times higher spectral resolution in the EUV than was previously available.

Our operational objective for the 1994 EUVS Venus flight was to obtain an EUV survey spectrum of Venus with ~ 5 times better spectral resolution than was previously available (Hord *et al.* 1991). With a spectral resolution similar to the 6.5 \AA terrestrial EUV spectrum obtained by Gentieu *et al.* (1981), we planned to (i) reveal new, previously-unresolved emissions from photoelectron-stimulated C, O, N, N^+ , N_2 , and CO emissions, (ii) refine aeronomical models of the thermosphere of Venus, and (iii) address the discrepancy between Venera 11/12 measurements and entry probe measurements of Ne/Ar.

Figure 1 shows an EUV spectrum of Venus obtained by the EUVS rocket instrument at 6.4 \AA resolution, after removal of the telluric foreground and conversion to brightness units (Stern *et al.* 1996). The error bars shown are the root-sum-square of the uncertainties due to counting statistics, observing geometry, and detector background. Figure 2 shows the EUVS spectrum of Venus, smoothed to 30 \AA resolution (bold line) for a comparison to the Galileo UVS Venus spectrum (Hord *et al.* 1991), which is shown as a thin line. Some nine distinct spectral features are evident at $> 3\sigma$ confidence in the spectrum shown in Figure 2. Four of these features have been assigned confident identifications, including the first identifications of neutral and charged nitrogen in Venus' spectrum, and new measurements of the brightness of the HI (1026 \AA), OI (989 \AA), and OII (834 \AA) emission features. The other five features received tentative identifications which require higher spectral resolution to discriminate between possibilities. Clearly, the EUV spectrum of Venus has been revealed to be rich in spectral features.

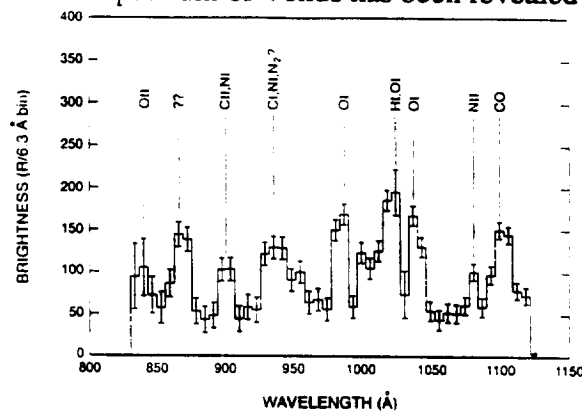


Figure 1. The EUV spectrum of Venus obtained by the EUVS rocket instrument (flt. 36.117CL) at 6.4 \AA resolution, after removal of the telluric foreground and conversion to brightness units. The error bars shown are the root-sum-square of the uncertainties due to counting statistics, observing geometry, and telluric foreground. Tentative identifications are shown above the strongest features.

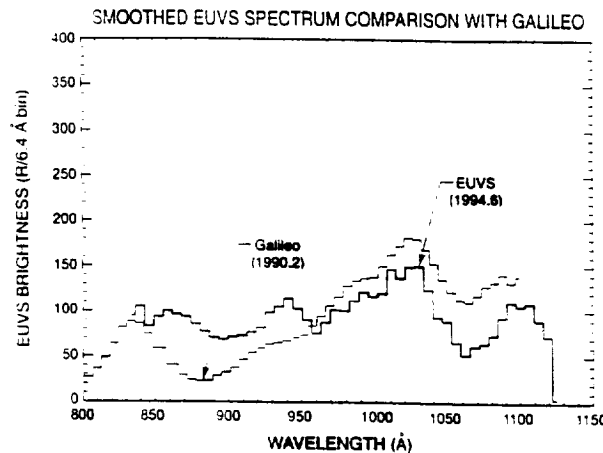


Figure 2. The bold line shows the EUVS spectrum of Venus shown in Figure 1, smoothed to 25 Å resolution, in order to match the Galileo Venus spectrum. The Galileo spectrum available to us is shown as the thin line, is not absolutely calibrated, and was arbitrarily scaled (see Stern *et al.* 1996).

To make further progress in the study of Venus' EUV spectrum, we plan to fly the EUVS payload in the summer of 1996 with a spectral resolution of ~ 3 Å. This is ~ 2 times better spectral resolution than the 1994 Venus flight (36.117CL) spectrum shown in Figure 1. This new dataset will allow us to explore the EUV spectrum of Venus to a degree not achievable by any existing or foreseeable observation.

We shall fly the EUVS payload in the same configuration as it was flown on its 1994 Jupiter and Venus flights, and its last flight to observe the occultation of Spica by the Moon (36.137CL). The new spectrograph entrance slit will have a width of 289 μm , which will yield a spectral resolution of 3.1 Å (FWHM) with the existing 2400 g/mm grating (slit image convolved with the detector's resel size). The grating will be tipped to center our 900-1130 Å spectral passband for this flight onto the science detector.

3. THE EUV TELESCOPE/SPECTROGRAPH

3.1 Payload Configuration

The payload configuration of the EUV telescope/spectrograph (EUVS) is shown in Figure 3. It consists of the NASA supplied vacuum door, telescope, spectrograph, fine guidance camera, electronics section, and various support systems. Five skin sections contain the entire payload. The forward end of the EUVS instrument payload is defined to be at the tip of the electronics section; the aft end of the instrument is at the vacuum door end of the telescope section.

The telescope is a diamond-turned $f/15$ Wolter Type II grazing incidence telescope with an entrance aperture 30 cm in diameter. The light from the telescope is focused onto the entrance slit of a normal incident Rowland circle spectrograph. The spectrograph employs a spherical diffraction grating with a radius-of-curvature of 400.7 mm. The detector is placed on the Rowland circle with its input face normal to the

ATTACHMENT B

EUVS FLIGHT 36.117CL SCIENTIFIC PAPER

TARGET: VENUS

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NOTE

The 825–1110 Å EUV Spectrum of Venus

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On 15 August 1994 we launched the EUVS sounding rocket payload to observe the 825–1110 Å region of Venus's far ultraviolet airglow spectrum. The EUVS telescope/spectrograph obtained good data at five times higher spectral resolution than was previously available in the far ultraviolet. We present these data and compare our results to those obtained by the Galileo UVS and Venera 11/12 UV spectrophotometers. We identify several new spectral emission features, including both singly ionized nitrogen and molecular nitrogen in Venus's spectrum. We also see evidence for electron-impact-induced emission from CO. Finally, the EUVS data indicate that the "Ar" emissions detected in Venus's far ultraviolet spectrum by Venera 11/12 spectrophotometers are in fact not due to argon, thus eliminating the discrepancy between *in situ* and remote sensing measurements. © 1996 Academic Press, Inc.

Introduction. We are conducting a program of rocket-borne sub-orbital research observations to make spectroscopic studies of cometary and planetary atmospheres at far ultraviolet (FUV) and extreme ultraviolet (EUV) wavelengths, using the unique capabilities of the EUVS telescope/spectrograph which we have constructed. This report presents the first results of our August 1994 Venus observations.

The short-wave region of the ultraviolet which EUVS can observe is a rich one for the study of planetary targets (e.g., Bowyer and Malina 1991). Major NASA missions such as EUVE, Spacelab/ASTRO, and the Far Ultraviolet Spectroscopic Explorer (FUSE, scheduled for launch in 1998) attest to the importance of this waveband for astrophysical and planetary studies. Until FUSE flies, EUVS is the only instrument with the capability of making repeated planetary measurements in the region 750–1200 Å located between EUVE's long-wavelength cutoff and Hubble Space Telescope's short-wavelength cutoff.

The spectrum of Venus below 1200 Å has not been well studied in the past (cf. Fox and Bougher 1991). Indeed, the only observations obtained prior to those reported here were low-resolution spectrophotometer data from the 1974 Mariner 10 (Broadfoot *et al.* 1974) and 1978 Venera 11

and 12 Venus flybys (Bertaux *et al.* 1981), and the low-resolution spectra obtained during the 1990 Galileo Venus flyby (Hord *et al.* 1991). Those observations detected several strong EUV emissions from Venus's upper atmosphere, but at low resolution many of the embedded features could not be resolved.

A qualitative comparison of high-resolution terrestrial EUV dayglow spectra (Gentieu *et al.* 1981) with the unresolved "continuum" in the low-resolution Galileo Venus EUV spectrum indicated to us that high-resolution observations of Venus in the EUV could reveal a spectrum as rich as its telluric counterpart. Support for the anticipated richness of Venus's EUV spectrum was also generated because Venus's atmosphere, like the Earth's, contains significant populations of O, N, and N₂, which have complex EUV fluorescence spectra; Venus's atmosphere also contains significant abundances of the EUV-fluorescing species CO₂, CO, and C. As a result, we dedicated the August 1994 flight of the EUVS to studies of Venus.

Our objectives for the EUVS Venus flight were to obtain an EUV survey spectrum of Venus with ≈ 5 times better spectral resolution than previously available. With a spectral resolution similar to the 6.5-Å terrestrial EUV spectrum obtained by Gentieu *et al.*, our goal was to obtain the data necessary to put Venus EUV aeronomy on a par with terrestrial studies for the first time. This dataset can also provide new emission diagnostics to refine aeronomical models of the thermosphere of Venus, and potentially reveal new, previously unresolved emissions from photoelectron-stimulated C, O, N, N₂, and CO emissions.

2. Instrument and flight description. At 03:25 UT on 15 August 1994 the EUVS instrument payload was successfully launched on a Black Brant IX sounding rocket from White Sands, New Mexico, to obtain spectra of Venus in an ≈ 300 -Å EUV bandpass centered near 985 Å. The EUVS payload (Slater *et al.* 1995) has been previously used to study the response of the jovian aurora and Io plasma torus to the comet Shoemaker-Levy 9 impacts (Stern *et al.* 1995). It consists of an EUV telescope, an associated spectrograph, and its accompanying detector, power system, and telemetry electronics. The telescope is a diamond-turned f/15 Wolter type II grazing incidence design, with a 30-cm aperture (cf. Cash *et al.* 1989). The primary mirror is Ni coated; the secondary is SiC coated. Light from the telescope is focused onto a spectrograph entrance slit which is optimized for each mission. The EUVS spectrograph is a 0.4-m, normal-incidence Rowland circle design. For the Venus flight, the entrance slit, spectrograph, and grating combined to produce a characteristic plate scale of 13.9 Å mm⁻¹. The spectrum was measured using a 2-D resistive-anode (Ranicon) detector with an active area measuring 25 mm in diameter; the Ranicon's microchannel plate was coated with a KBr photocathode sensitive to our wavelength region of interest. To alleviate outgassing and detector protection concerns, the 184-kg telescope and spectrometer are launched under vacuum.

By making observations of Venus with two different slits, we obtained spectra at resolutions of both 6.4 and 16 Å. Because each of these slits was much longer (100") than Venus ($\sim 22''$), we directly obtained information on bright telluric (H I and O II) and interplanetary (H I) foreground emissions in the EUVS bandpass. As seen from Earth, Venus was 53% illuminated on 15 August 1994; its diameter was 22.1 arc seconds. The Earth-Venus relative velocity was -13.8 km/s, which produced a 45-mÅ blueshift in the middle of our bandpass. Since the Doppler widths of telluric thermosphere lines are typically only a few milliangstroms wide, this blueshift was sufficient to prevent strong absorption of Venusian spectral features by corresponding lines in the Earth's upper atmosphere.

At apogee the payload was at 255 km and the zenith angles of Venus and the Sun were 86.7° and 109.7°, respectively. Owing to the proximity of the Sun to both Venus ($\sim 45^\circ$) and the Earth's horizon ($\sim 4^\circ$), it was known before flight that the onboard star tracker could not be used to acquire Venus. Instead, we used the attitude control system gyros to guide the telescope to Venus, after gyro updates were made using a star tracker to acquire the stars Vega (α Lyr) and Arcturus (α

Boo). Fine pointing of the spectrograph entrance slit on Venus was accomplished by one of us (SAS) using real-time onboard fine guidance video images and a command link from the telemetry ground station at White Sands.

The data we describe below were obtained entirely when the payload was above 200 km. The bright B0V star Spica (α Vir) was observed after the Venus spectrum was obtained, in order to provide an inflight calibration of the instrument. Following the Spica observations, payload operations were halted in preparation for reentry and parachute deployment. The payload has since been successfully reflown to obtain 0.8-Å resolution EUV/FUV spectra of the lunar atmospheric occultation of Spica on 15 April 1995.

As noted above, two spatially offset slits were used during the Venus observations, a wide slit and a narrow slit. The wide slit's dimensions were 44.6" \times 100," which produced a resolution of 14–16 Å over its bandpass; the narrow slit dimensions were 22.3" \times 100" and produced a resolution of 6–7 Å. During the flight we sequentially centered each aperture on Venus with the slit's long axis oriented north-south. Since the half-energy width of the telescope is $\approx 45''$, Venus was not fully resolved in either slit. We obtained an integration time of 100 sec on the wide slit and 110 sec on the narrow slit. In this paper we report only on the higher-resolution dataset.

3. The 825–1110 Å spectrum of Venus at 6.4 Å resolution. The EUVS Venus spectra were reduced as follows. First, the detector background was determined from the areas of the detector on either side of the slit at every wavelength. This background was found to be $<1\%$ of the signal in the slit region. The instrumental flat field was determined by least-squares fitting the measured Spica calibration spectrum in each detector row to the reference Spica spectrum obtained by Brune *et al.* (1978).

The EUVS wavelength scale was established by a least-squares fit to a series of Pt-lamp lines imaged onto the detector before and after the flight. A shift of <3 Å was detected between these two calibrations. From the flight observations, we confirmed that the laboratory-derived wavelength scale agrees to within <3 Å of the positions of the 912-Å Interstellar Medium (ISM) H opacity cutoff in Spica's spectrum, and the 1026-Å H Lyman β geocoronal line.

A preflight effective area calibration was obtained using an O⁺/Ar resonance source at five wavelengths across the EUVS bandpass. We also obtained an in-flight calibration at all wavelengths between 912 and 1110 Å, using Spica as a standard. The Spica-derived effective area was found to agree in shape with our preflight laboratory calibration data in the region of overlap, but differed in scale by a factor of up to 1.5. In the region longward of 912 Å, we adopted a compromise effective area spectrum that is the approximate mean of the two calibrations; shortward of 912 Å we relied on laboratory datapoints and smoothly interpolated between them in wavelength. We estimate that the effective area of the EUVS instrument as flown on the 15 August 1994 Venus flight is known to 30–40% accuracy.

To remove strong telluric foreground emissions from O⁺ (834 Å) and the H Ly β /O I blend (1026–1027 Å), we subtracted the off-Venus emission recorded in our long slit. For weaker telluric emissions, we computed a model telluric foreground spectrum. These estimates of terrestrial airglow intensities were obtained using a modification of the procedure described by Gladstone (1994). Using a fine grid of positions along the line-of-sight from the rocket toward Venus, we employed models of the local atmosphere (MSIS-86; Hedin 1987) and ionosphere (IRI90; Bilitza 1990), along with photoelectron production and transport codes (Link 1992) and radiative transfer codes (Gladstone 1994) to calculate likely emission rates for telluric features due to neutral Ar (1067 Å, 1048 Å; photoelectron impact excitation), O (989 Å; photoelectron impact excitation), N₂ (c.f. 958 Å; photoelectron impact excitation), and O (911 Å; electron-ion recombination). The resulting emission rates were then integrated along the time-dependent line-of-sight of the flight trajectory to yield foreground brightness estimates.

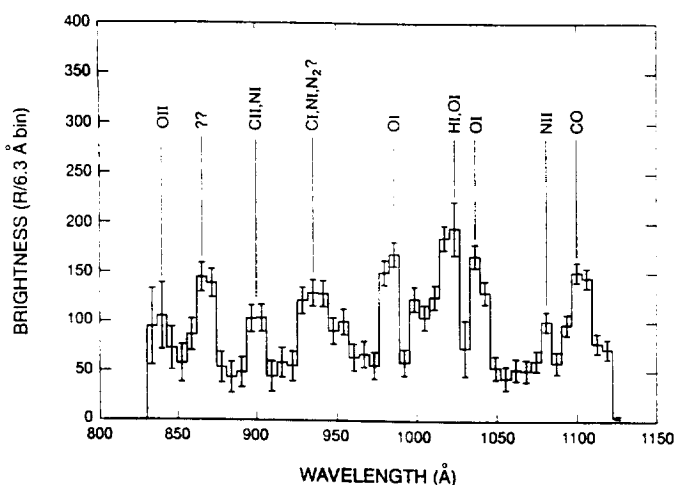


FIG. 1. Venus narrow-slit EUVS spectrum (15 August 1994). The line shows the EUV spectrum of Venus obtained by the EUVS rocket instrument at 6.4 Å resolution, after removal of the telluric foreground and conversion to brightness units. The error bars shown are the root-sum-square of the uncertainties due to counting statistics, observing geometry, and telluric foreground. Tentative identifications are shown above the strongest features; other information accompanying this figure is given in Table 1.

After subtracting away the estimated foreground signal, we converted the individual count spectra obtained to brightness units (Rayleighs per spectral bin) using the effective area of the instrument, the solid angle of each slit, and the slit filling factor of the sunlit hemisphere of Venus as seen from Earth. From this we obtained the brightness spectrum shown in Fig. 1, which are the standard deviation of the mean of the uncertainties due to counting statistics, background subtraction, and observing geometry. Effective area calibration uncertainties create an additional uncertainty in the absolute scale of 30–50%.

Prior to the time these data were obtained, the best EUV spectrum of Venus was obtained by Galileo: as discussed by Hord *et al.* (1991), the Galileo data resulted in the identification of only three features in this bandpass: 834 Å O II, 989 Å O I, and the 1026/1027 Å HI/OI blend. Several new features that were not seen or resolved in their spectrum are detected here at higher resolution. Figure 2 shows a direct comparison of our spectra to an arbitrarily scaled Galileo UVS spectrum. This Galileo UVS spectrum was kindly provided to us by I. Stewart and W. Pryor of the Galileo UVS team. The Galileo spectrum shown here is not absolutely calibrated and is useful solely for comparing the presence or absence of spectral features. In Fig. 2 we have smoothed our data to 25 Å resolution to approximately match the Galileo UVS resolution. Comparing the two datasets, we find strong similarities in the EUVS and Galileo spectra near 834 Å and longward of ~950 Å; however, the strong features near 867 and 940 Å seen in the EUVS spectrum have no counterparts in the Galileo spectrum.

In Table 1 we give background-subtracted brightness estimates for the most notable features in Fig. 1, and our candidate identification for each. The brightnesses quoted here are illuminated-disk averages, as measured at Earth, and have not been corrected to remove the effects of CO₂ absorption in Venus's atmosphere; as such they represent the emergent flux from Venus. The data presented in Fig. 1 and Table 1 contain the identification of new emissions attributed to N I, N II, N₂, CO, and possibly C I and C II.

We now briefly comment on the strong features in the spectrum shown in Fig. 1.

- **834 Å.** We identify this feature as the emission triplet from O⁺, which is the dominant high-altitude species in Venus's ionosphere. This emission had previously been detected by the Venera 11/12 and Galileo UV instruments. Our derived brightness is about 40% of the 180 ± 60 R reported by the Galileo team (Hord *et al.* 1991), which is consistent with the solar cycle-driven decline in solar ultraviolet flux from 1990.1 to 1994.6.

- **867 Å.** We have not yet confidently identified this distinct feature, which does not appear in the Galileo spectrum, or in previous modeling (e.g., Paxton 1990). The latter leads us to conclude that it is not due to the H, O, C, N, or N₂ species included in Paxton's model. The intriguing aspect of this feature is that it is at the same location that Bertaux *et al.* reported emission in the "argon" channels of his Venera spectrophotometer. Some fraction of this signal may derive from 869 Å fluorescence of neutral Ar, but the width of the feature is more suggestive of a molecular band. We discuss the feature again in Section 4 below.

- **902 Å.** We tentatively identify this feature as a blend of C II (904 Å) and N I (910 Å) lines, which Paxton's model predicts to have a combined brightness in the range of 25 to 60 R under moderate solar UV conditions. If the C II dominates this blend, it would represent an important remote sensing handle on ionized carbon at Venus.

- **940 Å.** The identity of this feature, which is not present in the published spectrum obtained by the Galileo EUV spectrometer, is not secure at this time. Our opinion is that the width of this feature argues for a molecular band or several closely spaced atomic lines. One potential contributor may be the C I (945 Å) resonance line, which Paxton (1990) estimates could be as bright as several kR, but which, owing to self absorption, may be as dim as a few tens of R. In addition, the 953-Å N I line may also be contributing; model predictions by Paxton suggest a potential 35–70 R brightness for this feature. Another possibility is the N₂ (*b*¹Σ–X¹Σ) system, which shows its strongest terrestrial airglow feature at this wavelength (Gentieu *et al.* 1981).

- **984 Å.** We associate this feature with the strong resonance multiplet of neutral oxygen at 989 Å. The 187 ± 38 R brightness we find for this feature is in good agreement with the 175–350 R O I (989 Å) prediction of Paxton's model, but is considerably higher than one would extrapolate from the 130 ± 30 R Galileo EUVS O I (989 Å) signal corrected to mid-1994 solar conditions.

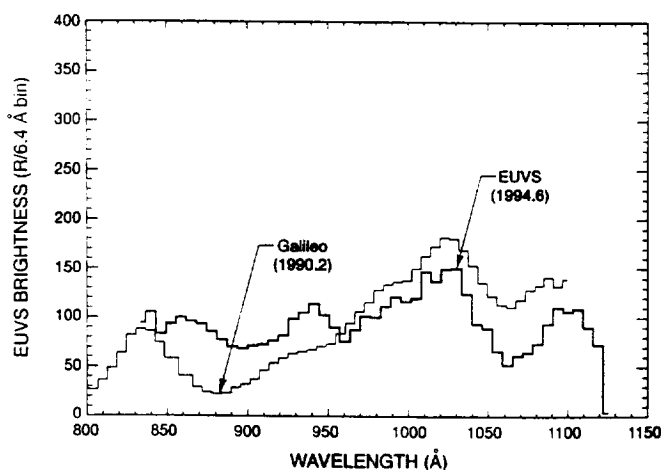


FIG. 2. Smoothed EUVS spectrum comparison with Galileo. The bold line shows the EUVS spectrum of Venus shown in Fig. 1, smoothed to 25 Å resolution, in order to match the Galileo EUVS Venus spectrum; the apparent changes in feature brightnesses from Fig. 1 are an artifact of this smoothing. The Galileo spectrum available to us is shown as the thin line, is not absolutely calibrated, and was arbitrarily scaled, as we describe in the text.

• **1000 Å.** Both the brightness and the location of this feature suggest that it is associated with the N_2 Birge–Hopfield band centered near 1009 Å. However, the narrow width and low statistical significance of this feature suggest it could be a data artifact.

• **1027 Å.** We associate this feature with the well-known H I Lyman β /O I blend at 1026/1027 Å. The Galileo UV spectrometer team reported a brightness of 270 ± 60 R for this feature, which is in relatively good agreement with our 152 ± 72 R result, after correction for the decline in solar flux between the two measurement epochs.

• **1038 Å.** We believe that this feature is most likely due to the emission of O I (1039 Å), for which Paxton estimated a brightness of up to 60 R.

• **1085 Å.** We identify this feature as the long-sought 1085-Å N II emission generated by e^- impact on N, and photoionization of N and photodissociative ionization of N_2 ; in the Earth's upper atmosphere, the latter process appears to dominate (Meier 1991). The Paxton model predicts a Venus N II 1085-Å brightness of 50–150 R, which is in good agreement with our derived brightness.

• **1100 Å.** This feature appears to have been seen in the Galileo data, but Hord *et al.* (1991) did not suggest an identification. We associate this feature with the broad electron impact-stimulated CO (C–X) emission band centered at 1088 Å. Although the 1100-Å wavelength peak in our data is a few angstroms more distant from 1088 Å than we would prefer, CO is the dominant molecule in Venus's thermosphere, and laboratory data (Kanik *et al.* 1995) show very clearly that this band makes a strong emission feature for e^- impact energies between 20 and 200 eV. If the feature is in fact due to CO, then we predict that the $\sim 60\%$ stronger B–X band CO emission at 1160 Å should be easily detectable in Venus spectra covering the 1150–1200 Å region.

4. **The 867- and 1038-Å emissions.** As a result of the Venera 11/12 flybys over 15 years ago, the Venera 11/12 UV team (Bertaux *et al.* 1981) identified significant emission in two, 20-Å-wide “argon” spectrophotometer bandpasses. These signals greatly exceeded the predicted argon emission brightness that should result from the atmospheric column of argon measured by *in situ* instruments aboard the Pioneer Venus entry probes.

In particular, the Venera 11/12 spectrophotometer team detected 55 and 133 R signals in their so-called “Ar I” channels at 869 and 1048 Å, respectively. This was surprising because the 30–110 ppm argon mixing ratios reported from the PV entry probe measurements (e.g., Hoffman *et al.* 1980, von Zahn *et al.* 1983) imply only ≈ 1 –3 R of emission at 869 Å and ≈ 0.3 –1 R of emission at 1048 Å. As such, the V11/12 measurements

imply 20–100 times more Ar than can be accounted for by PV's *in situ* measurements.

Because noble gases are highly useful tools for studies of the origin and evolution of planetary atmospheres, the stakes in the V11/V12 remote sensing versus *in situ* argon measurement issue are high. If the V11/V12 signal were indeed produced at precisely 869 and 1048 Å, it would cause a significant reexamination of ideas about Venus's primordial and radiogenic argon.

Our data can be used to address this discrepancy. As described in Section 3, the EUVS spectrum does indeed display an emission feature near 867 Å, and another near 1038 Å. We believe it is probable that the Venera 11/12 experiment bandpasses overlapped portions of these features. However, we do not ascribe these features to Ar emissions for the following reasons: (i) the features we detect are approximately two orders of magnitude brighter than expected for Ar I emission; (ii) the somewhat broadened nature of the feature near 874 Å is more consistent with an unresolved molecular band; (iii) the 1038-Å feature is better fit in wavelength space and can be adequately explained by the presence of the 1039-Å O I feature which should naturally arise in Venus's thermosphere (cf. Paxton and Anderson 1992); and (iv) no significant feature is present near 1066 Å, where Ar I also resonates. Therefore, although emission in the 869- and 1048-Å V11/V12 spectrophotometer channels have been detected by EUVS, we conclude that the generation of these emissions by Ar I is unlikely. The identification of the 867-Å feature remains an intriguing, open issue.

5. **Summary.** We observed Venus's 825–1110 Å spectrum at 6.4 Å resolution on 15 August 1994 using the EUVS sounding rocket spectrometer. The resulting spectrum has approximately five times higher spectral resolution than had been achieved prior to this experiment. The spectrum we obtained reveals that Venus is rich in EUV spectral features. Some 9 or 10 spectral features are apparent in the EUVS spectrum; most of these features have been assigned initial identifications, including the first identifications of N I, N II, and N_2 in Venus's spectrum, and the probable detection of the CO (C–X) band centered at 1088 Å.

Additionally, we have new measurements of the brightness of Venus's strong H I (1026 Å), O I (989 Å), and O II (834 Å) emission features detected by the Galileo EUV spectrometer. Although the H I and O II feature brightnesses derived from EUVS data are consistent with expectations from the Galileo EUV spectrometer, the O I emission brightness detected by the EUVS rocket payload is far higher than expected. This

TABLE I
Venus 825–1110 Å Spectral Features at 6.4 Å Resolution

Approx. central wavelength	Candidate identification	Brightness	Model prediction
0841 Å	O II (834 Å)	083 ± 32 R	500–1000 R
0867 Å	??	138 ± 25 R	None
0902 Å	C II (904 Å), N I (910 Å)	078 ± 14 R	25–60 R
0940 Å	C I (945 Å), N I (953 Å), N_2 (946 Å)?	175 ± 35 R	400–1000 R
0984 Å	O I (989 Å)	187 ± 38 R	175–350 R
1000 Å	N_2 (1009 Å)	056 ± 14 R	30–75 R
1020 Å	H I (1025 Å), O I (1027 Å), some S II (1028 Å)?	152 ± 72 R	100–400 R
1038 Å	O I (1039 Å)	170 ± 32 R	30–60 R
1085 Å	N II (1085 Å)	070 ± 15 R	50–150 R
1100 Å	CO (1090 Å)	109 ± 18 R	50–150 R

Note. Brightnesses for each feature are integrated over the full EUVS resolution function, after subtraction of the underlying background shown in Fig. 1. Owing to counting statistics, as well as wavelength resolution and binning effects, wavelength inaccuracies of up to 9 Å (1.5 spectral bins) can occur in extreme cases. The predicted brightnesses are from Paxton (1990) and Paxton and Anderson (1992).

discrepancy remains unresolved, but may be related to the uncertainty in our effective area calibration, or differences in observing geometry, or both.

Finally, our data indicate that the controversial emissions identified by Venera 11/12 spectrophotometry in bandpasses centered near 869 and 1048 Å are indeed present in Venus's spectrum: our higher-resolution data indicate they lie closer to 867 and 1038 Å. However, as discussed above, it is unlikely that these emissions are due to argon. Although the 867-Å feature in our data remains unidentified, the 1038-Å feature is most likely created by O I emission.

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Note added in proof. As we completed the revisions to this report, we became aware of an abstract and poster paper presentation by Feldman *et al.* (1995) revealing the preliminary analysis of a Venus spectrum that includes the 825–1100 Å EUVS bandpass with ≈ 4.5 Å resolution, obtained in March 1995 by the ASTRO/Spacelab observatory Hopkins Ultraviolet Telescope (HUT) instrument. Both similarities and differences exist between the EUVS and ASTRO/HUT data. The comparative analysis of these two datasets should be revealing.

REFERENCES

- BERTAUX, J.-L., J. E. BLAMONT, V. M. LEPINE, V. G. KURT, N. N. ROMANOVA, AND A. S. SMIRNOV 1981. Venera 11 and Venera 12 observations of EUV emissions from the upper atmosphere of Venus. *Planet. Space Sci.* **29**, 149–166.
- BILITZA, D. 1990. International Reference Ionosphere 1990. *NSSDC/WDC-A-R&S-90-22*. National Space Science Data Center, Greenbelt, MD.
- BOWYER, S., AND R. F. MALINA 1991. The Extreme Ultraviolet Explorer Mission. *Adv. Space Res.* **11**(11), 205–211.
- BROADFOOT, A. L., S. KUMAR, M. J. S. BELTON, AND M. B. McELROY 1974. Ultraviolet observations of Venus from Mariner 10: Preliminary results. *Science* **183**, 1315–1318.
- BRUNE, W. H., G. H. MOUNT, AND P. D. FELDMAN 1978. Vacuum ultraviolet spectrophotometry and effective temperatures of hot stars. *Astrophys. J.* **227**, 884–899.
- CASH, W. C., T. A. COOK, C. CHAMBELAN, D. HEYSE, D. HOFMOCKEL, T. P. SNOW, AND D. WINDT 1989. A far-ultraviolet rocket-borne spectrograph. *Exp. Space Sci.* **1**, 123–136.
- FELDMAN, P. D., S. T. DURRANCE, AND A. F. DAVIDSON 1995. Far-ultraviolet spectroscopy of Venus and Mars at 4 angstrom resolution with the Hopkins ultraviolet telescope on Astro-2. *Bull. Am. Astron. Soc.* **27**, 1027. [Abstract]
- FOX, J. L., AND S. W. BOUGHER 1991. Structure, luminosity, and dynamics of the Venus thermosphere. *Space Sci. Rev.* **55**, 357–489.
- GENTIEU, E. P., P. D. FELDMAN, R. W. EASTES, AND A. B. CHRISTENSEN 1981. Spectroscopy of the extreme ultraviolet airglow during active solar conditions. *Geophys. Res. Lett.* **8**, 1242–1245.
- GLADSTONE, G. R. 1994. Simulations of DE 1 UV airglow images. *J. Geophys. Res.* **99**, 11441–11448.
- HEDIN, A. E. 1987. MSIS-86 thermospheric model. *J. Geophys. Res.* **92**, 4649–4662.
- HOFFMAN, J. H., V. I. OYAMA, AND U. VON ZAHN 1980. Measurements of the Venus atmosphere lower composition: A comparison of results. *J. Geophys. Res.* **85**, 7871–7881.
- HORD, C. W., C. A. BARTH, L. W. ESPOSITO, W. E. MCCLINTOCK, W. R. PRYOR, K. E. SIMMONS, A. I. F. STEWART, G. E. THOMAS, J. M. AJELLO, A. L. LANE, R. M. WEST, B. R. SANDEL, A. L. BROADFOOT, D. M. HUNTEN, AND D. E. SHEMANSKY 1991. Galileo ultraviolet spectrometer experiment: Initial Venus and interplanetary cruise results. *Science* **253**, 1548–1550.
- KANIK, I., G. K. JAMES, AND J. M. AJELLO 1995. Medium-resolution studies of extreme-ultraviolet emission from CO by electron impact. *Phys. Rev. A* **51**, 2067–2074.
- LINK, R. 1992. Feautrier solution of the electron transport equation. *J. Geophys. Res.* **97**, 159–169.
- MEIER, R. R. 1991. Ultraviolet spectroscopy and remote sensing of the upper atmosphere. *Space Sci. Rev.* **58**, 1–185.
- PAXTON, L. J. 1990. *EOS* **71**, 430, [Abstract]
- PAXTON, L. J., AND D. E. ANDERSON 1992. Far ultraviolet remote sensing of Venus and Mars. In *Venus and Mars: Atmospheres, Ionospheres, and Solar Wind Interactions*. AGU Monograph 66, pp. 113–189.
- SLATER, D. C., S. A. STERN, J. SCHERRER, W. C. CASH, J. C. GREEN, AND E. WILKENS 1995. The extreme ultraviolet spectrograph sounding rocket payload: Recent modifications for planetary observations in the EUV/FUV. In *EUV, X-Ray, and Gamma-Ray Instrumentation for Astronomy VI* (O. H. W. Siegmund and J. Vallerger, Eds.), Vol. 2518, pp. 211–222. SPIE.
- STERN, S. A., D. C. SLATER, W. CASH, E. WILKENS, J. C. GREEN, AND G. R. GLADSTONE 1995. Rocket FUV observations of the Io plasma torus during the Shoemaker–Levy/9 impacts. *Geophys. Res. Lett.* **22**, 1837–1840.
- VON ZAHN, U., *et al.* 1983. Composition of the Venus atmosphere. In *Venus* (D. M. Hunten, L. Colin, T. M. Donahue, and V. I. Moroz, Eds.), pp. 229–430. Univ. of Arizona Press, Tucson.

